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SHIPBOARD SUN SONDE TEST OF AAP SPIN ANGLE ERROR

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U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND

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ABSTRACT: This report describes the results of the AAP Sun Sonde Test aboard the USS MACON in September 1952. These results are substantially in agreement with those of the Naval Electronics Laboratory model study, conducted in 1952, and with the spin angle error assumptions used in recent AAP effectiveness studies.

The reliable performance of the electronic gear, and the excellent cooperation of the ship resulted in a very high percentage of usable and significant records. However, due principally to the extreme calmness of the sea, and the differences between AAP and 8"/55 trajectories, these results cannot be considered as a conclusive measure of the ultimate spin angle error of the AAP, and a need for further investigation is indicated.

U. S. NAVAL ORDNANCE LABORATORY
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The Shipboard Sun Sonde Test which resulted in the data presented here was conducted by the Missiles Division under task NOL-Re4c-117-1-53. The scope of the test was such that a majority of the personnel of the division took part either in the shipboard phase or in developing the instrumentation. The analysis of the records as well as the compilation of the data presented here, was performed largely by the Morris Engineering Company, and was directed and checked by A. M. Johnson and C. W. Kettenbach of the Missiles Division.

Further details of the Sun Sonde technique, shipboard instrumentation and methods of data analysis are presented in internal reports.

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Captain, USN
Commander

D. S. Muzzey, Jr.
D. S. MUZZEY, JR.
By direction

CONTENTS

ILLUSTRATIONS

REFERENCES

(a) NOLR 1175 - Feasibility of Small Ship AAP - Secret - 30 January 1953

(b) NAVORD Report 2856 - Model Measurements of AAP Spin Angle Error Caused by Shipboard Receiving Antenna Environment - Confidential - S. J. Raff

SHIPBOARD SUN SONDE TEST OF SPIN ANGLE ERROR

INTRODUCTION

Significance of Data

1. The Angled Arrow Projectile is a slowly rotating high velocity arrow shell capable of one angular trajectory correction during flight. This trajectory correction is accomplished by the command firing of a short burning-time rocket which thrusts at right angles to the trajectory. The shipboard computer, by extrapolating target and missile coordinates, determines the optimum time and direction in which to command the missile and accomplish the trajectory correction. The steering rocket has a fixed orientation with respect to the missile and the correct direction of thrust is achieved by giving the deflection command at the precise instant when the missile is in the proper rotational position. It is, therefore, basic to the system that the shipboard guidance equipment have continuous information on the instantaneous rotational position of the missile in flight. Further, the accuracy of this information is a prime factor in the accuracy of the system, and its effectiveness. The AAP Sun Sonde Test was conducted aboard the USS MACON to evaluate the accuracy of this rotational position information under actual shipboard conditions.

2. This rotational position information is derived by the shipboard translator from a cw radio signal transmitted by the missile and modulated only by the rotation of the missile and its antenna pattern. The missile antenna pattern, characteristics of the received signal, and mode of operation of the translator are described in reference (a). For present purposes, however, it should suffice to point out that the basic radiating element in the missile is a loop antenna. The plane of the loop contains the missile axis of rotation, and rotates about that axis as the missile rotates. Consider for simplicity Figure (1), the missile flying horizontally, rotating slowly about its axis with the loop antenna, also rotating, transmitting a cw signal back to the ship. The polarization of this signal will depend on the orientation of the loop. If the plane of the loop is vertical, the polarization (E vector) of the backward radiated signal will be vertical; if the plane of the loop is horizontal, the polarization of the radiated signal will be horizontal. The shipboard receiving antenna is vertically polarized, and its received signal will be a maximum when the polarization of the radiation reaching it is also vertical. Likewise, the received signal will be zero when the polarization of the radiation is horizontal. The translator, by electronic means, selects the times at which the received signal is a maximum and recognizes that the spin angle or rotational position of the

missile at that time is such as to make the loop plane vertical. There remains, of course, a 180-degree ambiguity in rotational position because so far the translator can only recognize vertical and horizontal and cannot tell up from down or right from left. The resolution of this ambiguity is accomplished by a slight modification of the missile antenna pattern caused by a longitudinal electric dipole (reference (a)). The basic accuracy of the rotational information, however, depends on the recognition of the polarization of the received signal. It may appear from Figure 1 that this polarization recognition is a simple process capable of very high accuracy; however, this figure is an over-simplification since it omits the antenna environment. The signal received by the shipboard antenna does not arrive pure and undistorted from the missile. A portion of the signal is reflected from the sea surface before arriving at the antenna, and part of it bounces off the ship's deck and superstructure. These reflected signals may change polarization radically on reflection and cause considerable differences in the polarization of the total signal arriving at the antenna. The effect of these reflected signals on the purity of polarization of the received signal and on the AAP accuracy has been, until recently, a major uncertainty in the AAP program. The complex structure of the ship and sea surface is, of course, not amenable to calculations.

3. In most recent AAP effectiveness studies such as reference (a) it has been assumed that the over-all root mean square error in steering is 10% in rocket thrust magnitude and 1/10 radian or 5.7 degrees in thrust direction about the trajectory. This 5.7 degree rms error is composed principally of the polarization errors discussed here. In fact, the constitution of this rms error was considered to be approximately 5 degrees due to polarization impurity, 2 degrees due to translator error, and 2 degrees due to computer error.

$$5^2 + 2^2 + 2^2 = 5.7$$

Note that the total rms error, which is statistically significant as the σ or standard deviation of the impact point, is the square root of the sum of the squares of the independent component errors. This estimate of 5.7 degrees or 1/10 radian was based somewhat on theory and on the results of Dahlgren field tests.

4. Rough theoretical studies also indicated that the AAP antennas would have to be stabilized, train with the director and retain a uniform elevation of about 30° regardless of the gun or missile elevation.

Naval Electronic Laboratory Model Studies

5. From August 1952 to January 1953, a program was conducted through the cooperation of BuShips at the Naval Electronics Laboratory in San Diego to study these polarization errors and determine the optimum antenna location on a model cruiser. A detailed description of this study and the results thereof is given in reference (b). A scale factor of 48 to 1 was used with a smooth metal ground plane representing the sea surface. Instead of modeling the AAP antenna, a wave guide horn of the same beam width was used.

6. In order to select the most suitable antenna location, three locations were tested; one on the bow, one atop the number two 8"/55 turret, and one atop the forward Mk 37 director. The complete ranges of antenna train, 0 to 150 degrees, and missile elevation, 0 to 45 degrees, were investigated for each location. This study indicated an over-all rms error averaged over the train and elevation of 4.8 degrees for the director antenna, 3.4 degrees for the turret antenna and 2.8 degrees for the bow antenna. The accuracy of these measurements was estimated as ±1 degree. There appeared to be a significant increase in error with increasing angles of train beginning at an angle of 120 degrees from the bow. There also appeared a small increase in rms error at the lower missile elevations.

The Sun Sonde Technique

7. The AAP Sun Sonde was developed early in the program for the evaluation of accuracy of missile rotational information. It consists essentially of a regular AAP sonde with a longitudinal slot which admits sunlight to a photocell (Figure 2). The combination is so arranged that the sonde behaves normally, transmitting rotational information by polarization in the normal way, except that whenever the slot sweeps past the sun, a sharp pip of frequency modulation occurs. Thus, a sun sonde gives two independent rotational position indications. One is the normal polarization maximum indication whose accuracy we wish to evaluate, and the other is the position of the sun pip which is considered accurate and used as a standard for comparison. The angular difference between these two indications is measured from the record, and is called the measured lag angle (see Figure 3). From the geometry of the trajectory and the sun's position, the theoretical lag angle is then computed. This is the true angle between the vertical and the sun in the plane of missile rotation. The difference between theoretical and measured lag angle is then considered to be the error in the AAP rotational information. Figure 4 is a plot of theoretical and measured lag angle vs time from a sun sonde shot.

SCOPE OF SHIPBOARD TEST

8. During the week of 15 September 1952, 35 sun sondes were fired from the #2 turret of the USS MACON. The sondes were fired in regular 8"/55 inert projectiles rather than in AAP. By reducing the gun propellant charge to 10 pounds, the initial velocity of these rounds was held to 900 ft/sec, and their spin rate became of the same order of magnitude as that of the AAP. This was done so that the recording and analysis of the sun pips and sonde signature would not be unnecessarily complicated by a high projectile spin rate.

9. Vertically polarized antennas similar to those which will ultimately be used in AAP were mounted on the bow, #2 turret, and Mk 37 director, (Figures 5, 6, and 7). In addition, a helical antenna of the type used to command AAP was mounted on deck at the starboard rail alongside the #2 turret. This helical receiving antenna was used to check, by reciprocity relations, the power required to command the AAP from shipboard. A horizontally polarized antenna was also used to check certain theoretical aspects of the sea reflection. It was mounted on deck at the starboard rail forward of the #1 turret. The signals from these five antennas were transmitted (after pre-amplification and conversion) to an instrument truck lashed on the deck aft, where they were recorded (Figures 8, 9, and 10). Recordings were made of the pitch and roll of the ship by motion picture photography of the dials of the Mk 41 Mod 0 stable vertical in the main plotting room. However, these records were of little value. The sea was extremely calm during the test, so that the pitch and roll motion of the ship were of the order of 1 or 2 degrees. The method of photographing the Mk 41 dials was such that these small motions could not be accurately measured.

RESULTS OF SHIPBOARD SUN SONDE DATA

General Character of the Records and Interpretation

11. Lag angles between the major maximum (sonde indicated vertical) and the sun pip have been measured on 51 recordings. A portion of a typical plot of theoretical and measured lag angles as a function of time for a single antenna and single sun sonde round is shown on Figure 4. This plot is for round E3-83 fired at elevation 39 degrees, train 00 degrees, recorded from the turret antenna. Only 21 records were read and plotted in such detail. The remainder were sampled at each tenth point, and the samplings were considered to be representative of the entire record.

12. Figure 4 illustrates the general nature of the errors. There is a slowly varying error of about 1 second period, and superimposed on this is a rapid fluctuation of period about

one-tenth second. It is believed, on a theoretical basis, that the slow period fluctuations are due to scattering from the ships superstructure in conjunction with reflections from a smooth sea. The rapid fluctuations are believed due to a combination of sea roughness and instrumentation errors, with a very small amount being due to inaccuracy in reading the traces. The principal contribution to the root mean square average error is made by the slow fluctuations. For example, in Figure 4 the smooth curve was drawn by eye so as to average out the rapid fluctuation. The rms error value over the complete smoothed curve is 2.9 degrees while the rms error over the unsmoothed curve is 3.3 degrees; hence, the rapid fluctuation contributes only 0.4 degrees to the rms error. Other rounds analyzed in this way have shown similar error breakdowns. Since this rms error, assuming a normal error distribution, is the standard deviation or sigma of the steering, it can be concluded that the slow variation (due principally to scattering from the ships structure) is the primary cause of steering direction dispersion.

Over-all Results - Train and Elevation

13. Table 1 is a complete summary of all the rounds analyzed. The rms values are tabulated for each round and each antenna along with other pertinent information. Those rounds for which the antenna beams were not elevated are tabulated separately since these are not part of the main body of data, but were run to confirm the theoretical and NEL results that the 30-degree antenna beam elevation was superior to zero elevation. This confirmation is apparent. The rms values of error for each antenna, averaged over all rounds, is also presented in Table 1. These over-all values confirm the NEL indication that the director location is the worst of the three and indicate that the turret and bow locations are equivalent. Similar over-all figures from the NEL data are presented in Table 1 for comparison.

14. The data in Table 1 has been averaged for each antenna over all of the rounds fired at the same angle of train. Figure 11 presents this data in the form of rms error vs angle of train for each antenna. Here again the NEL trend (larger errors at the larger angles of train) is confirmed. It should be noted that for the 150 degree shots the bow antenna was mistrained 5 degrees which may account for a large part of the error increase at 150 degrees for that antenna.

15. There is no apparent effect of missile elevation on the rms values of spin angle error. This fact is somewhat difficult to illustrate since the elevation of each missile varies over its trajectory. Figure 12 illustrates the angular error (measured lag angle minus theoretical lag angle) as recorded from the turret antenna from 3 rounds fired at 10 degrees elevation.

The three rounds shown are among those in which only each tenth point was measured in order to shorten the analysis work. These plots indicate no significant increase in spin angle error as the rounds approach the water. The splash points are noted and the curves are carried to within about 100 feet of the water.

The Translator Prediction Problem

16. The experimental lag angles which have been compared with the theoretical to obtain Figures 4, 11, and 12 and Table 1, were measured as described in Figure 3. In obtaining this lag angle, no attempt was made to simulate the AAP translator operation or to find the spin angle error which an actual translator would make in deriving spin information from the received signal (Figure 3). Of course, the operation of an actual translator is beyond the scope of this report, but it must be recognized that in obtaining the measured lag angle we have used a procedure which is not available even to a perfect translator. We have checked our theoretical lag angle against a measured lag angle obtained by interpolation. An actual translator must extrapolate instead of interpolating since its task is to select in advance the correct time at which to command. It is of no value to know the correct time after that time has passed,Therefore, it cannot base its computation on the time of occurrence of succeeding peaks.

17. The translator, in practice, keeps a running record of the interval between AM peaks, and predicts the rotational position using the time of occurrence of the last peak, and the rotational rate which it has stored from preceding cycles. This stored rate may be an average of several preceding cycles, or merely the rate of the last complete cycle. In any case the translator prediction must be based on the rate of preceding cycles, and not on that of the present one. In fact, the situation is somewhat complicated by the rocket and filter delay. The filter delay and burning time of the rocket in the AAP missile are such that the command to steer must be given about 90 degrees before the portion of the signal corresponding to the correct missile spin angle appears at the translator. Therefore, the translator must predict spin angle from 90 to 450 degrees in advance. For example, if it is desired to steer at 89 degrees past a particular AM peak, the command must be given 1 degree before the peak appears in the translator determined by measurements involving still earlier peaks.

18. Figure 13 presents a more realistic method of predicting the spin angle error of a perfect translator. Measured lag angle (1) is based upon spin rate during the preceding cycle and measured lag angle (3) is based on the average spin rate during the three preceding cycles. A short section of record ES-84 has been analyzed by these two methods and Figure 14 presents the results, comparing them with the method used for

the remainder of the data in this report, as described in Figure 3. No significant difference is apparent. This lack of significant difference is fairly understandable since it is to be expected on a theoretical basis that the change from the interpolation to extrapolation would serve to accentuate the rapid fluctuation in measured lag angle (Figure 4) while having little or no effect on the slow fluctuations. Since the slow fluctuations constitute the major component of the error, an increase in the amplitude of the rapid fluctuation should have little effect on the root mean square until the two types of fluctuation become comparable. However, over a rougher sea surface, it is possible that the rapid fluctuation may become comparable to or greater than the slower fluctuations, in which case the extrapolation required of the translator may result in considerably larger errors than measurements by interpolation would indicate.

19. It should be noted that if the rapid fluctuations are greater, the accuracy of the perfect translator in selecting a steering angle will depend on the angle to be selected; i.e., the length of the interval from the last peak over which the translator must extrapolate. The data in Figure 14 presents the error inherent in predicting the theoretical lag angle of 150 degrees, and is representative of the best third of the range of spin angles. The sun sonde data does not lend itself readily to determining the prediction accuracy for angles other than the theoretical lag angle, and the range of theoretical lag angles during the sea test was less than 20 degrees.

20. It is recognized that the sample of data presented in Figure 14 is small in view of its direct bearing on the accuracy of the AAP spin angle prediction. However, further pursuit of this question would be misleading since it is necessarily beyond the scope of the MACON test for the following reasons. First, the uniform calmness of the sea during the test cannot be considered representative of the water surface in general. Sea roughness would be expected to increase the higher frequency component of the error which is amplified by the translator prediction. Second, variation in missile rotation rate would be expected to have a large effect on translator prediction accuracy, and this variation is not likely to be comparable for the finned AAP and the spin stabilized 8"/55. Third, the difference between the AAP trajectories and that of the 8"/55 projectile at 900 ft/sec, and the number of feet of travel along these trajectories per spin rotation, are radically different. These differences may make radical changes in the nature of the sea reflection effect and in the periodicity of the errors as measured in spin cycles, which will directly affect the translator prediction accuracy.

CONCLUSIONS AND RECOMMENDATIONS

21. Figure 15 presents a pertinent portion of an AAP kill study made in the Weapons Analysis Division of NOL. The target and director data are taken from an actual S-1 type plane run at the Chesapeake Bay Annex of the Naval Research Laboratory. The gun orders were taken from a Mk 1 computer, and the steering orders from an analogue of the AAP computer. The ballistic dispersion was assumed to be 2 mils. The three curves illustrate the effect of steering inaccuracy. The curve labeled 10% corresponds to 5.7 degrees rms spin angle error, 20% corresponds to 11.4 degrees error, and 30% corresponds to 17.1 degrees error. In order to preserve a circular normal distribution of steering errors for simplicity of calculation, the dispersion in rocket thrust was assumed to increase with increasing spin angle error, the percentages of error being the same. The curves are for one rapid fire 8" barrel firing one round each 6 seconds. The data of Table 1 indicate that with the AAP receiving antenna in the turret location, the system performance will be somewhere between the top and center curve. However, this conclusion has been arrived at by experimentation with an unusually calm sea, and ignoring the difficulty that the translator cannot interpolate, but must predict the correct spin angle in advance. On the other hand, it should be stated that the antennas now under design for AAP use are superior to those used in this test. In particular they will have narrower beams, and be less sensitive to reflected and scattered signals. There is also theoretical evidence that a considerable improvement will result from the decrease in body-to-loop phase angle which is now being engineered in the sonde, and some improvement may result from filtering of the signal before it enters the translator. In passing, it should be noted that of the three types of runs made at CBA, S-1, E-1 and Helical, the S-1 run, which is the only one analyzed for the effect of steering accuracy, is probably the least sensitive to steering errors.

22. The results of this sun sonde test indicate that the AAP steering accuracy will be very close to the 10% initially assumed; however, it must be recognized that these results are not conclusive. It is recommended that a higher degree of confidence in AAP steering accuracy be achieved by conducting an additional sea test before drone firings are attempted.

23. The development of a sabot for rifled barrel launching of AAP makes it feasible to conduct the test with AAP missiles carrying the sun sondes. The test should be conducted with considerably rougher sea conditions. If possible, a closer approximation to the final shipboard antenna should be used, and the body-to-loop phase of the sondes should be held within the tolerances for the final sonde design.

24. Only one vertical antenna mounted atop the turret need be used, but the antenna mount should be stabilized. The received signals should be recorded on magnetic tape so that they can subsequently be used to check the performance of the final AAP translator. In view of the exceptionally trouble-free performance of the electronics on the MACON test, it might be advisable to carry a translator on this projected test.

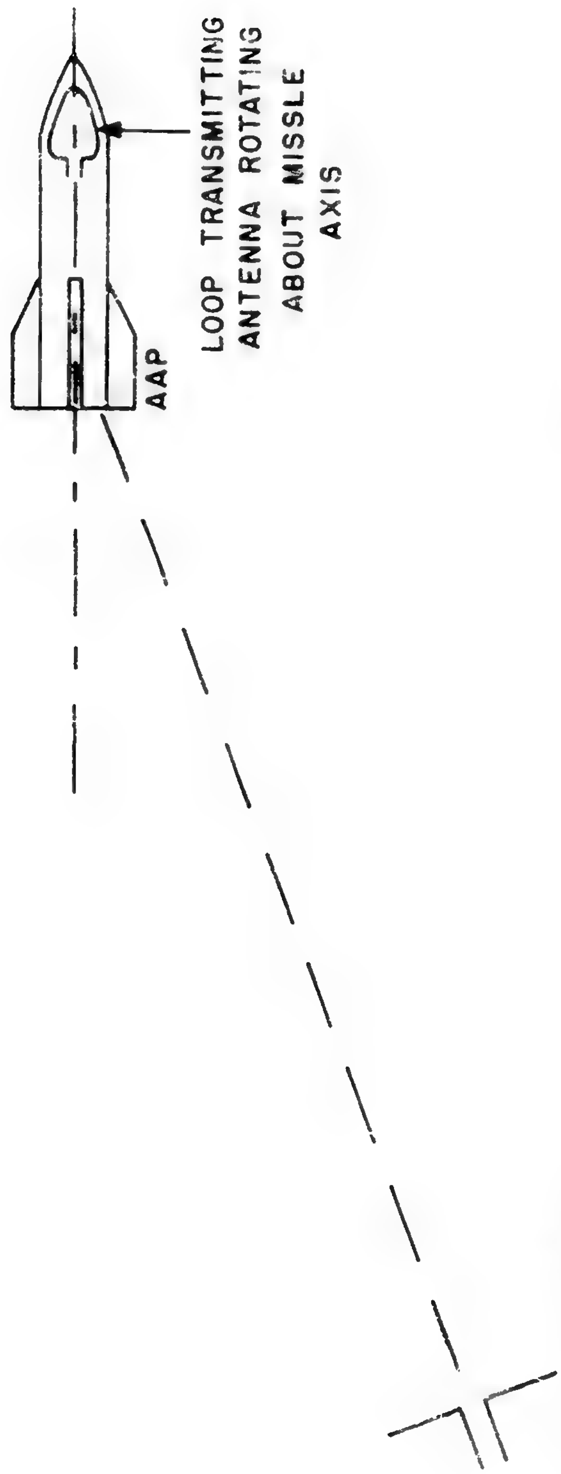


FIG. 1
MISSILE TO SHIP RADIO LINK

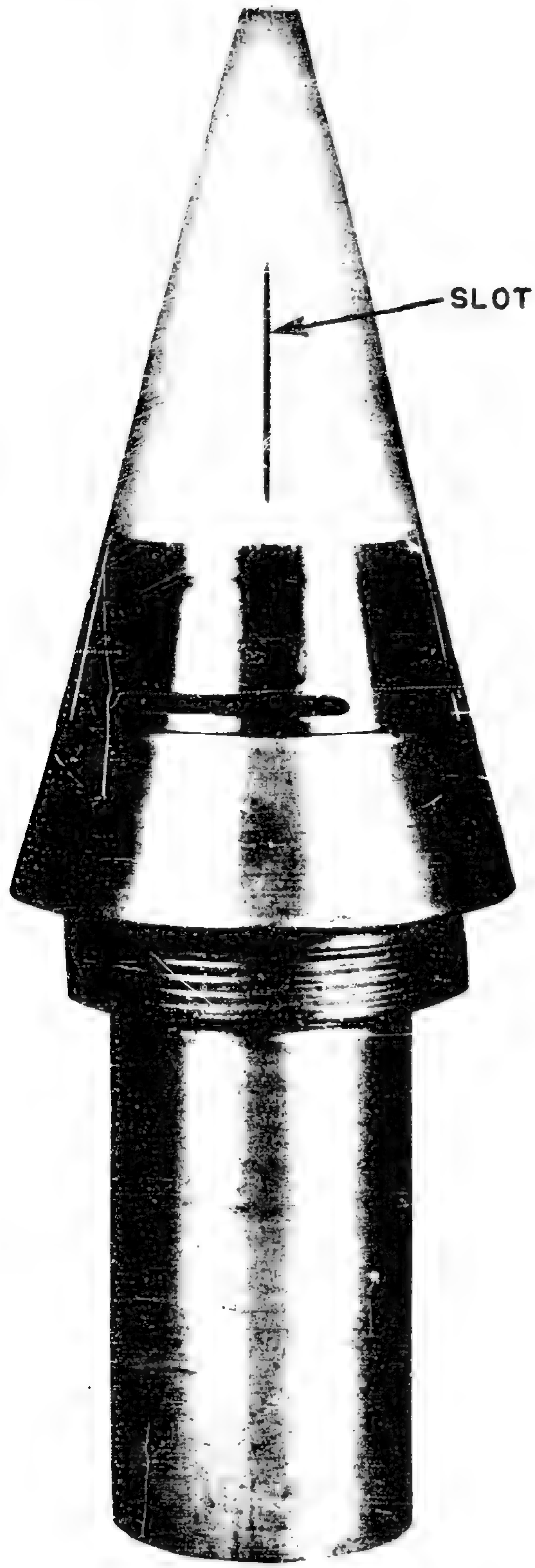


FIG. 2 AAP SUN SONDE

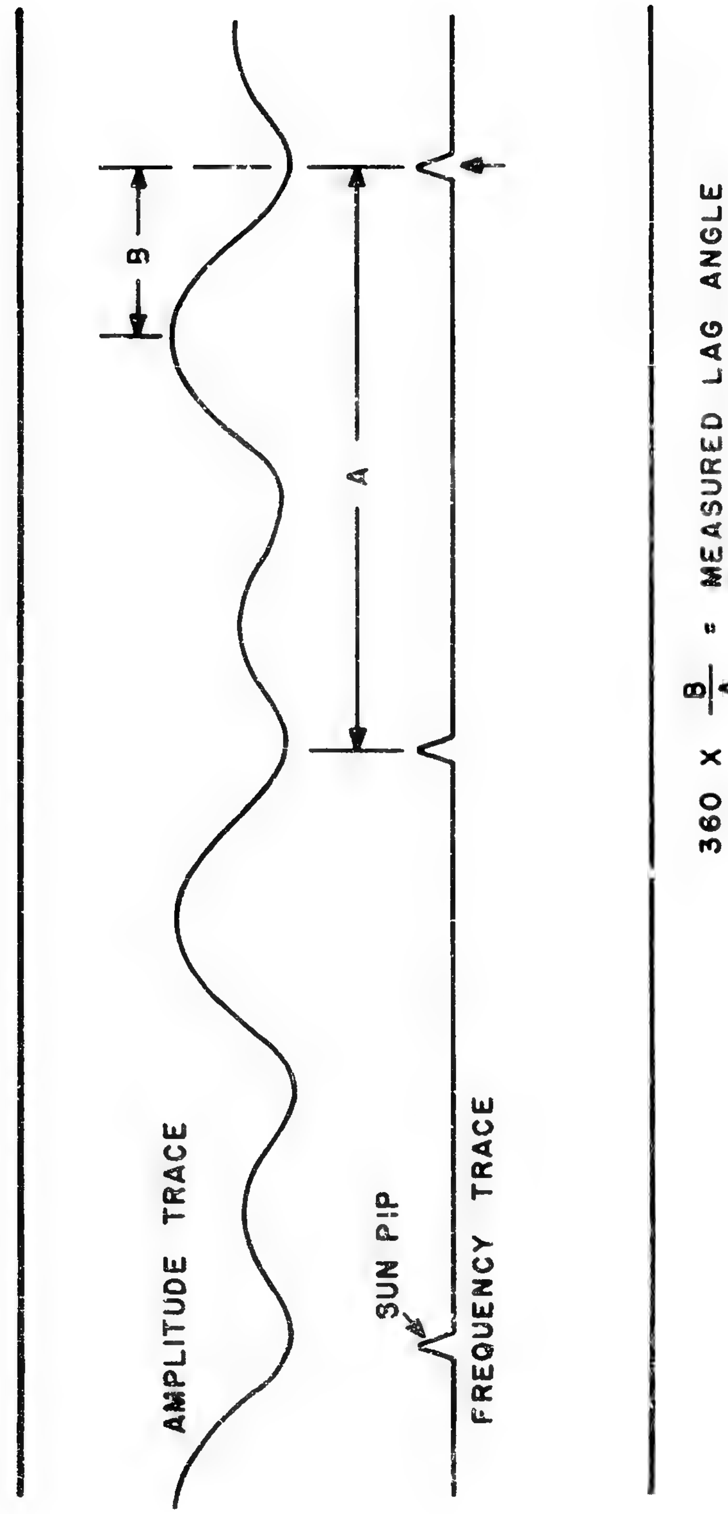
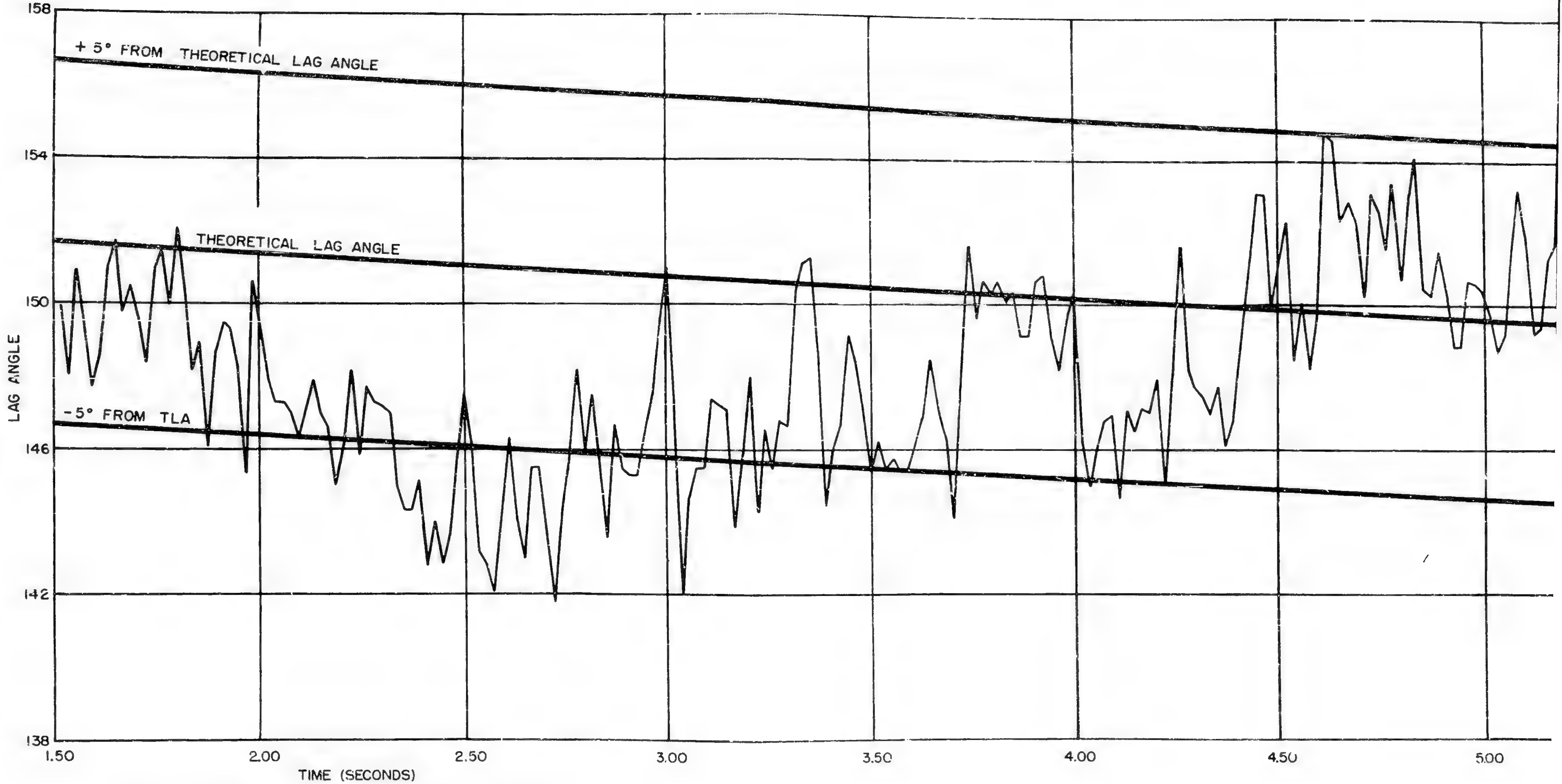
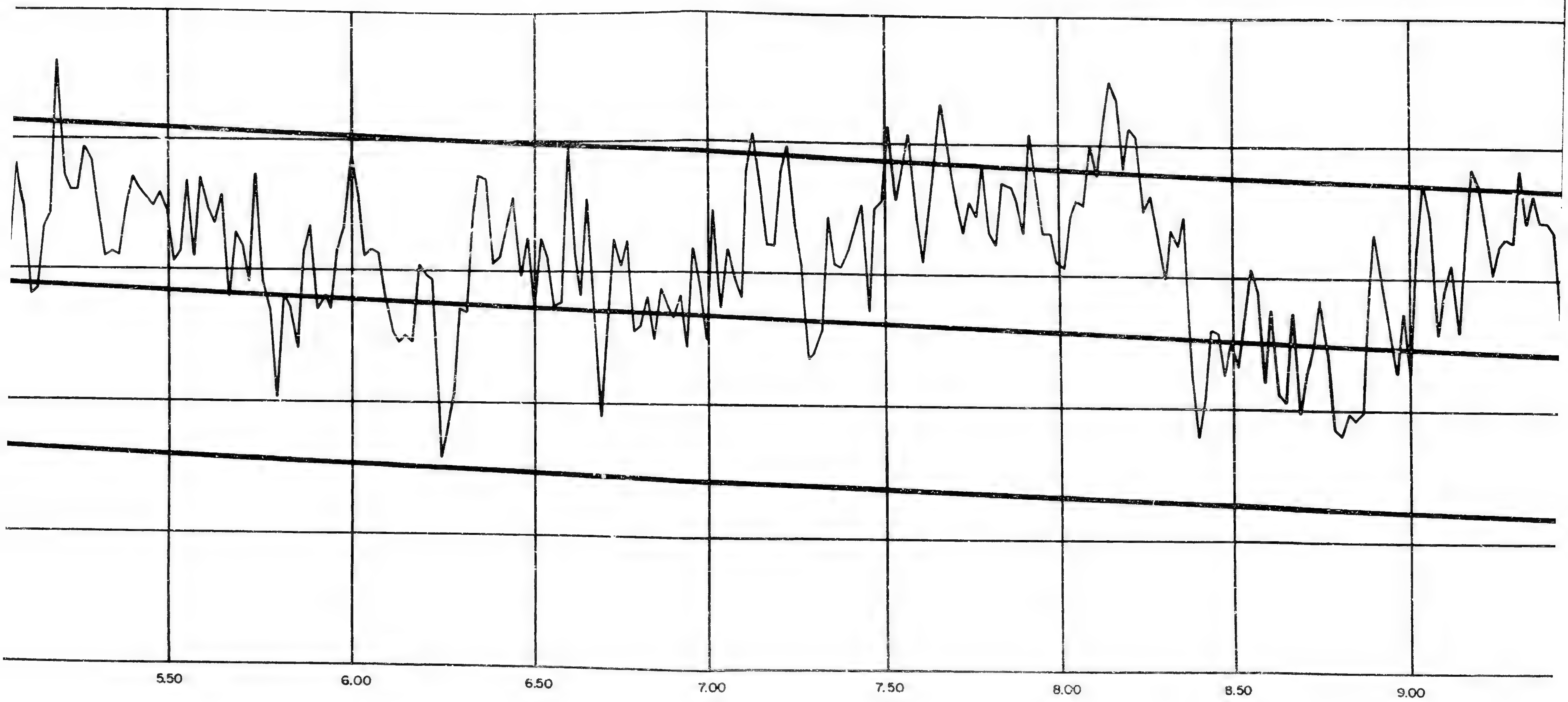
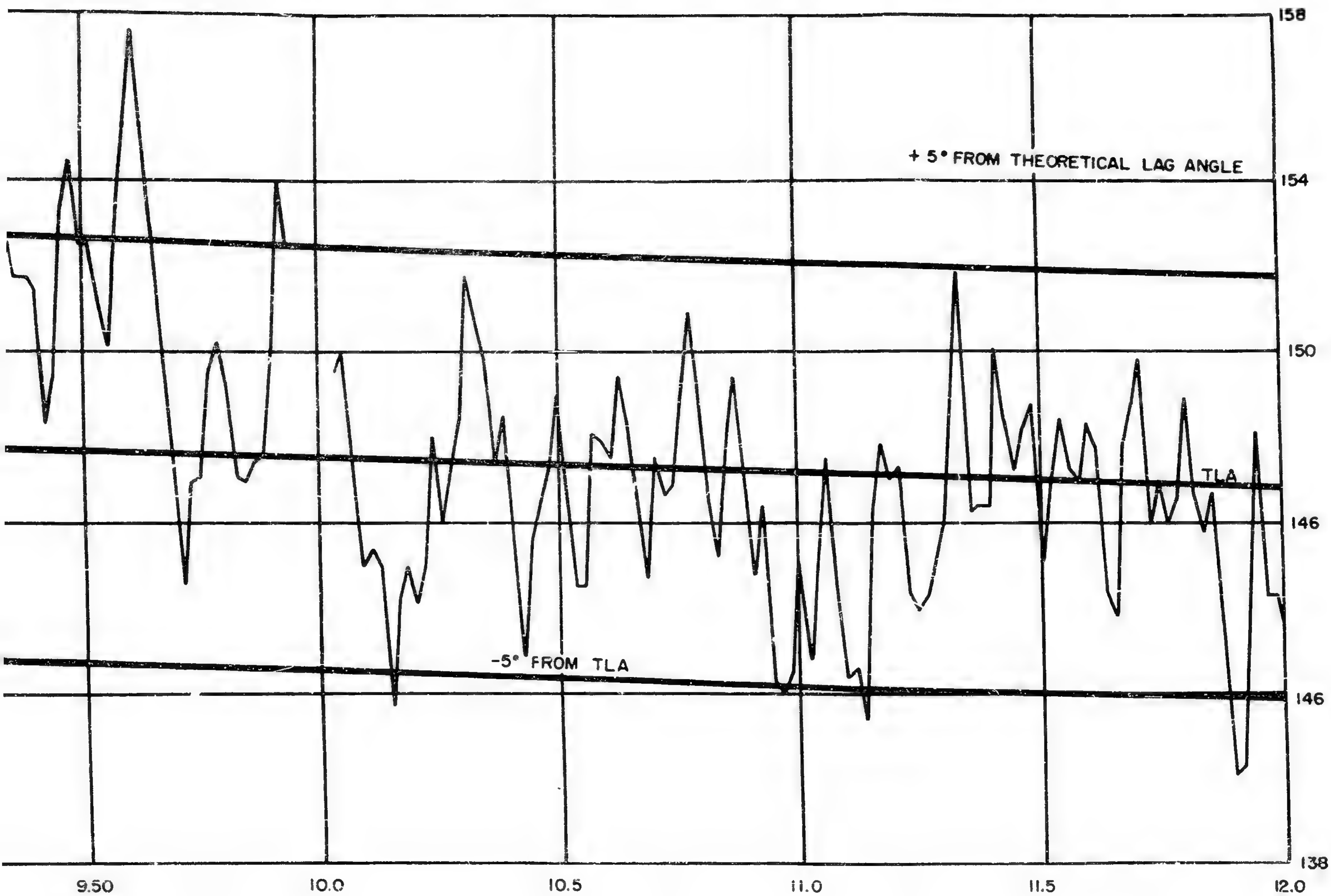


FIG. 3 TYPICAL OSCILLOSCOPE RECORD



ES 84 VERTICAL TURRET LAG ANGLE VS TIME
FIG. 4


5.50
6.00
6.50
7.00
7.50
8.00
8.50
9.00



+ 5° FROM THEORETICAL LAG ANGLE
TLA
-5° FROM TLA
158
154
150
146
146
138
9.50
10.0
10.5
11.0
11.5
12.0

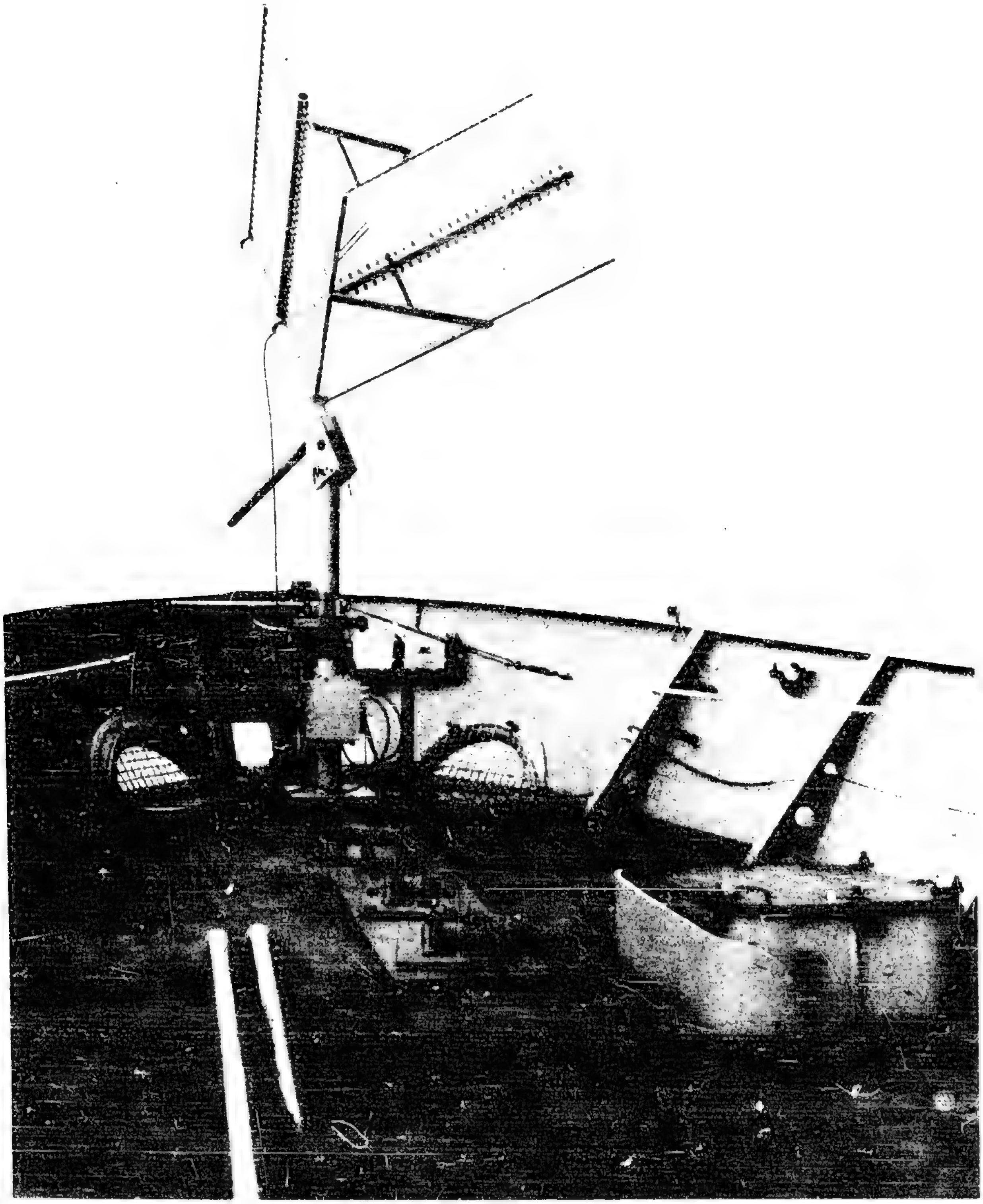


FIG. 5 VERTICAL BOW ANTENNA

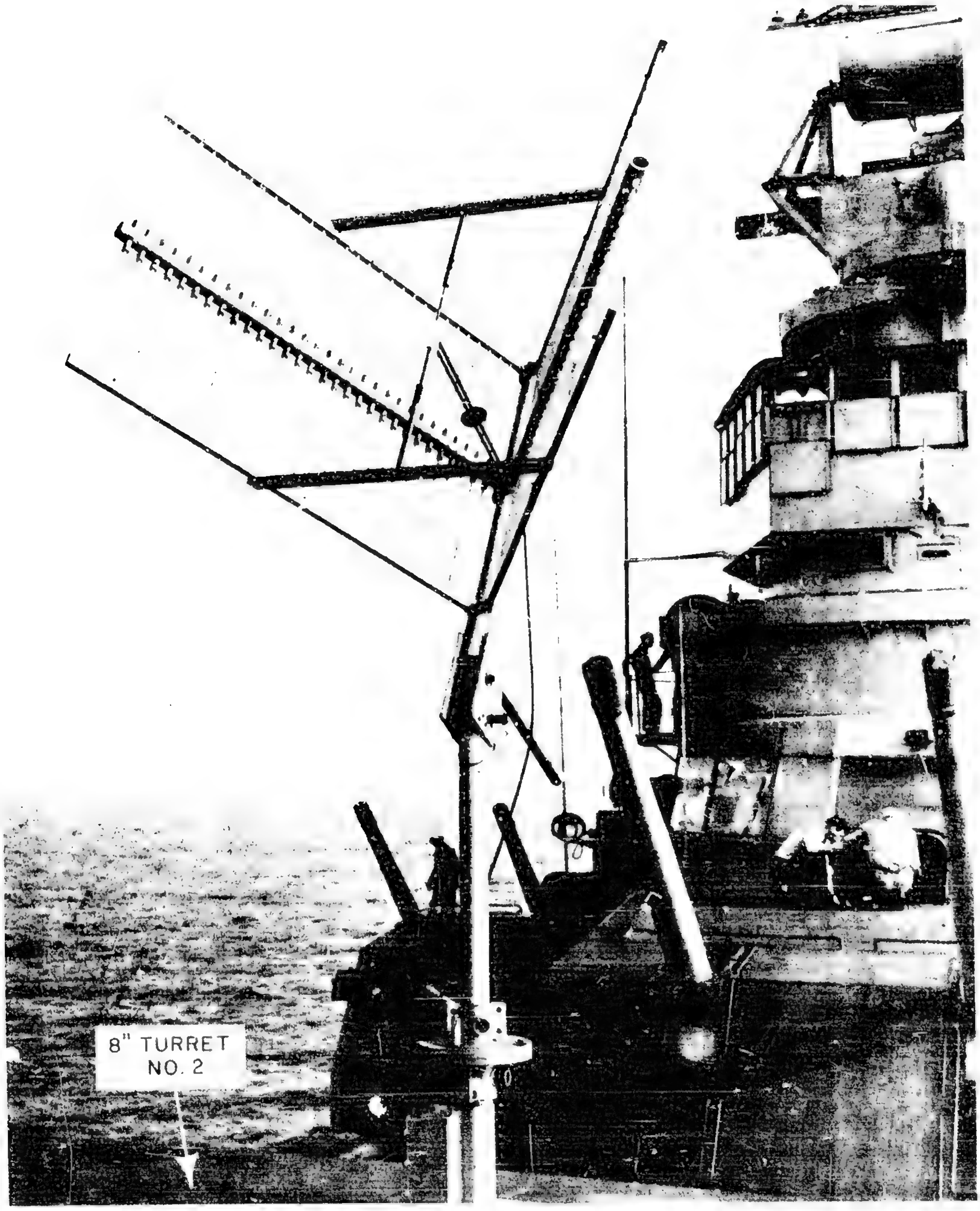


FIG. 6 TURRET ANTENNA

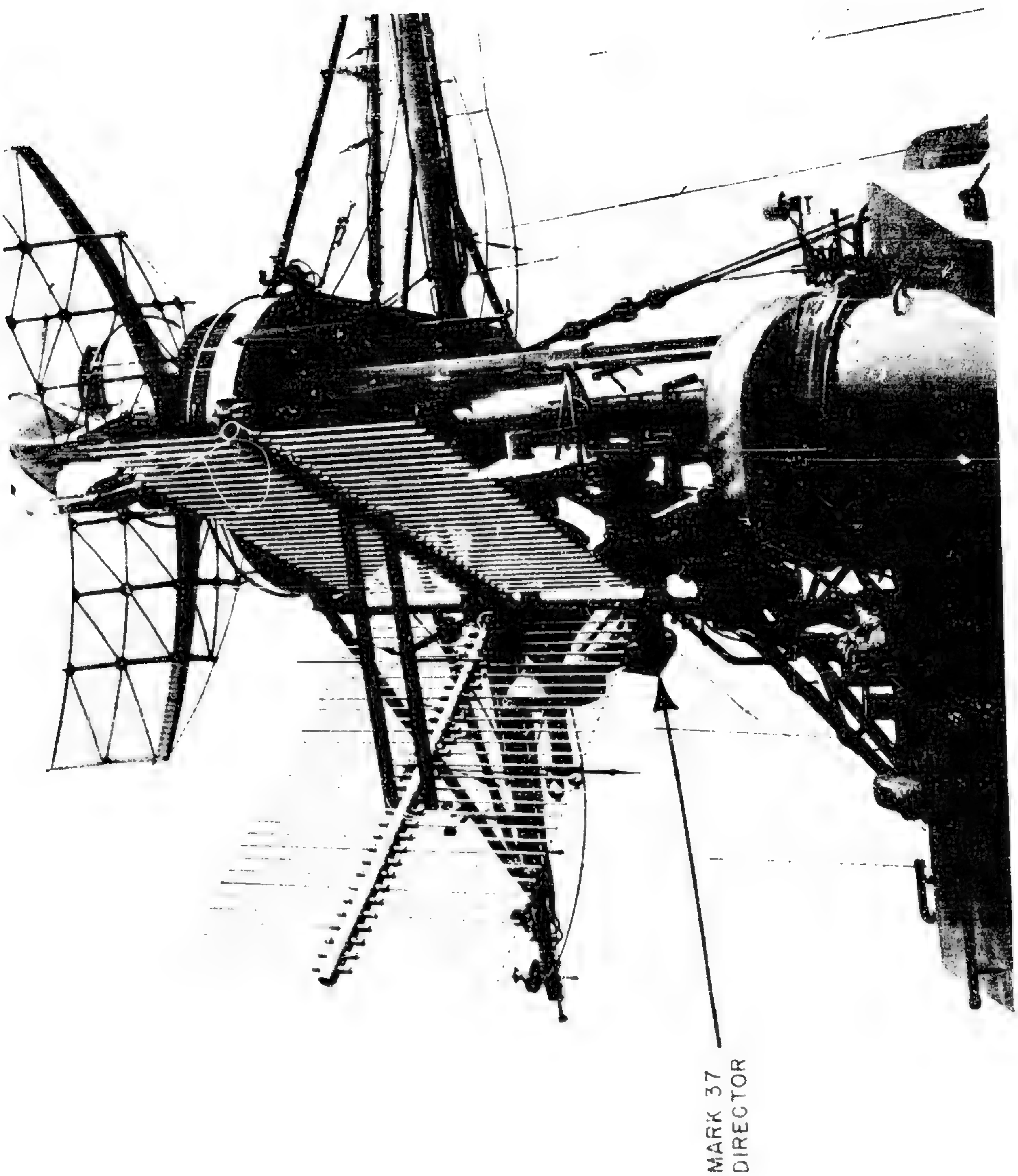


FIG. 7 DIRECTOR ANTENNA

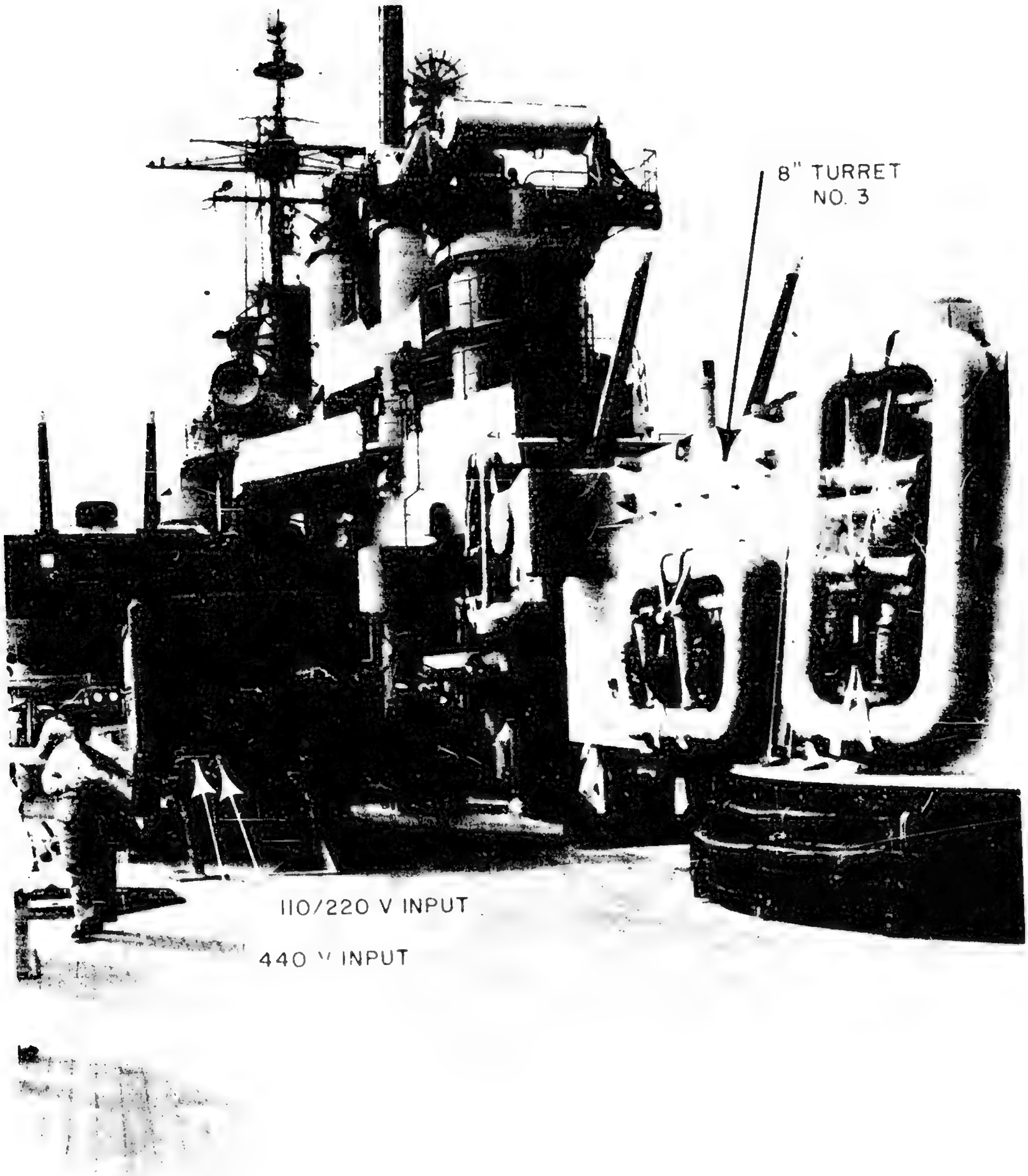


FIG. 8 TRUCK LOCATION

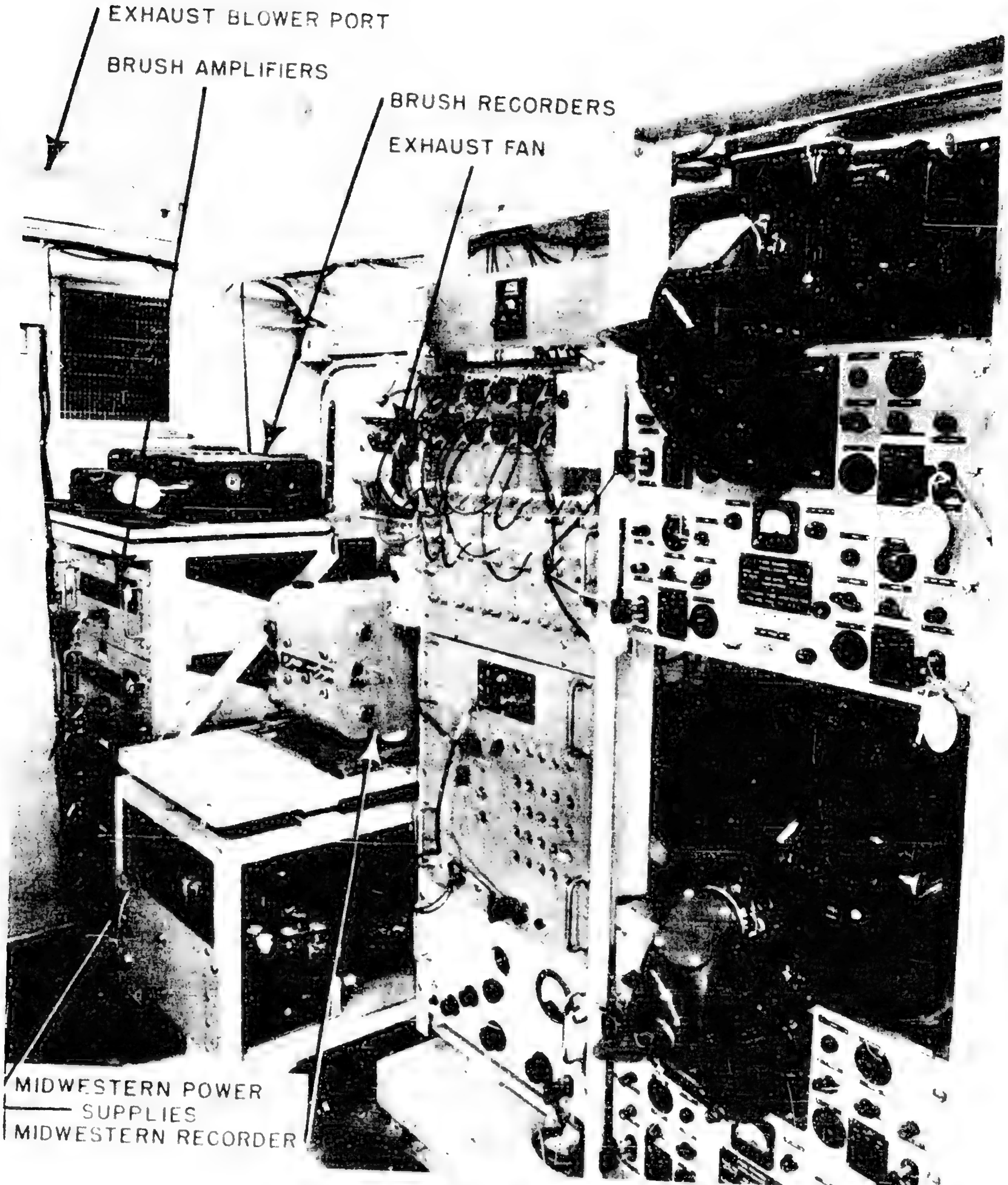


FIG. 9 TRUCK INTERIOR
(MIDWESTERN RECORDER AND BRUSH RECORDERS)

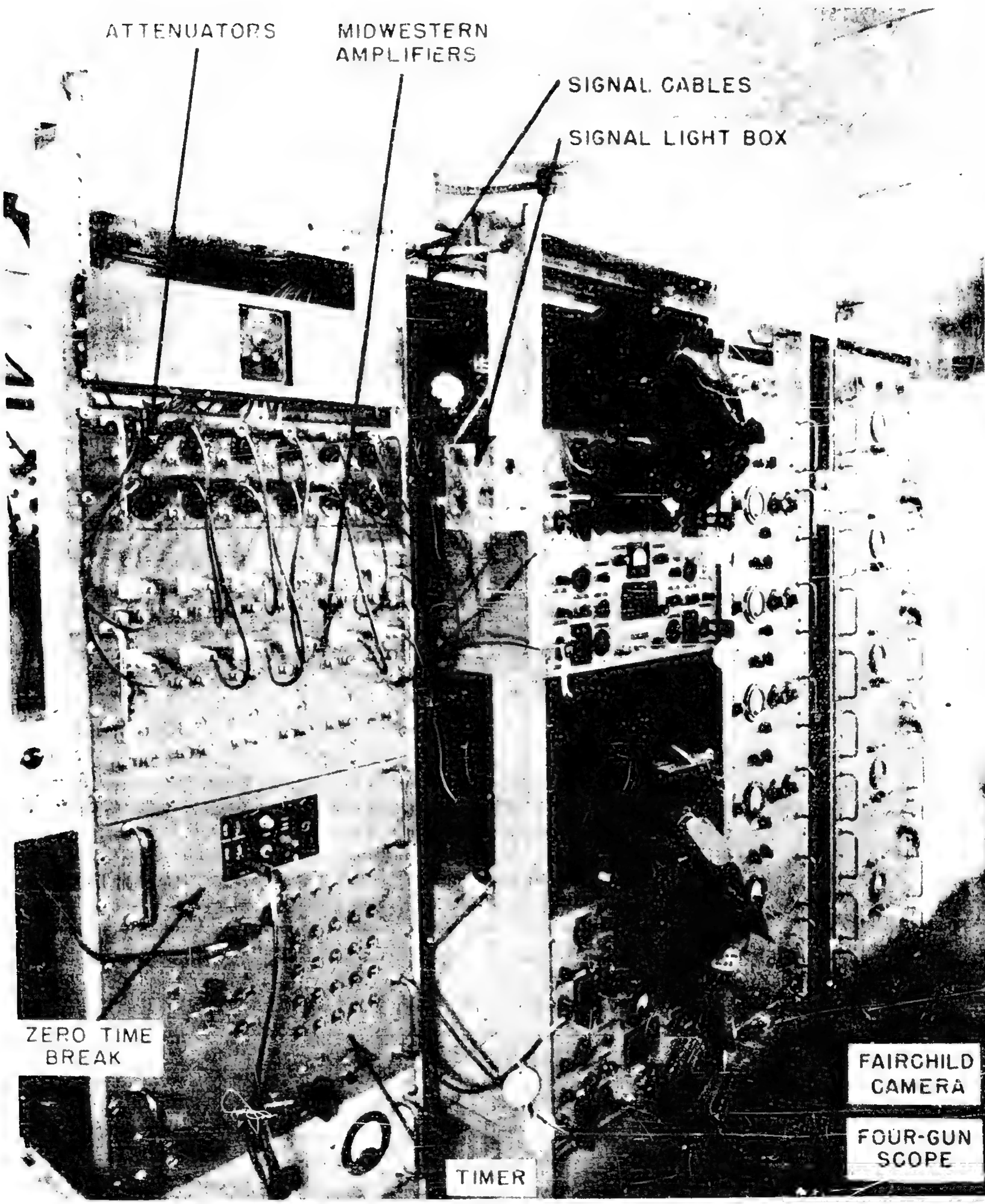


FIG. 10 TRUCK INTERIOR
(FOUR GUN SCOPES)

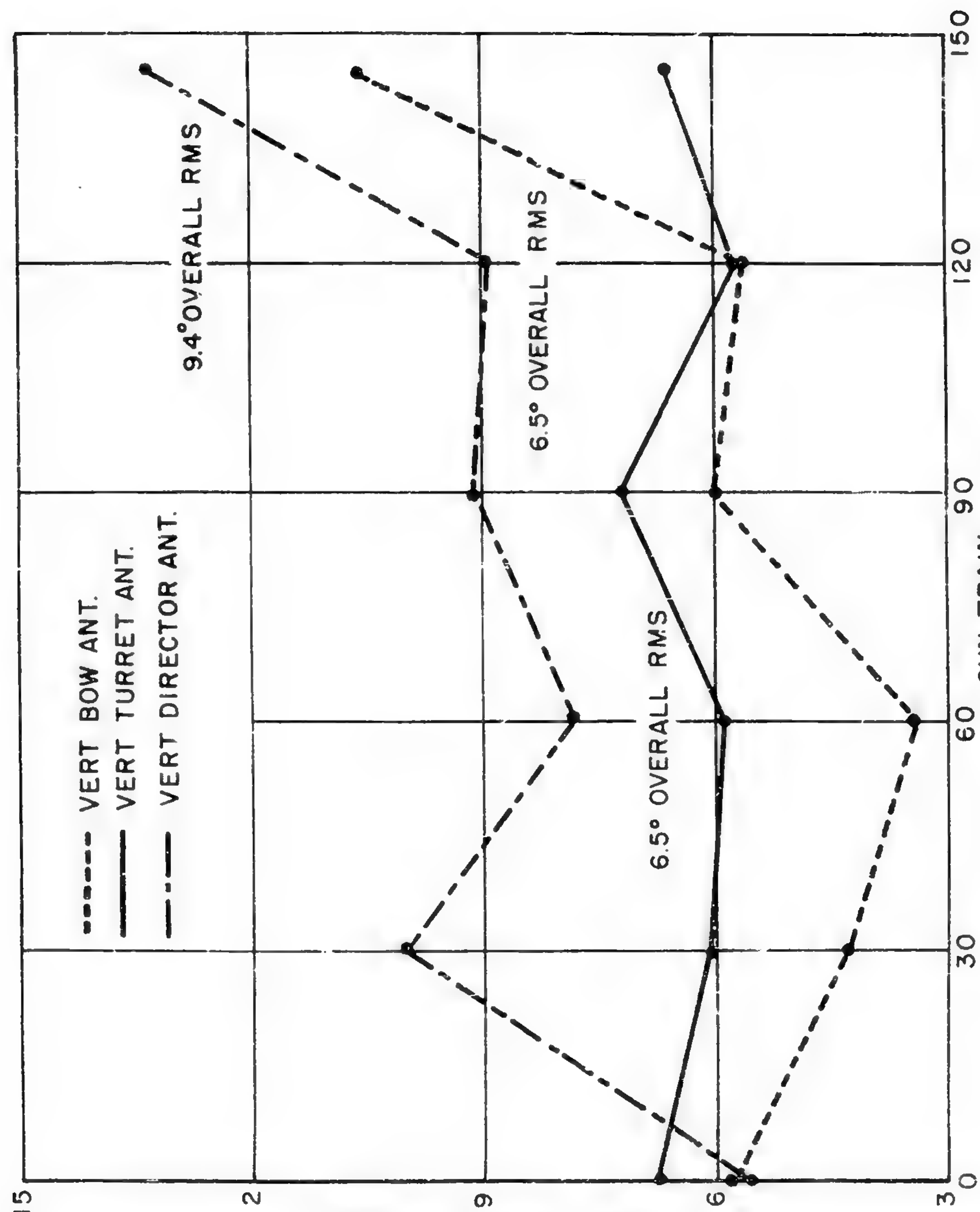


FIG. 11 RMS ERROR VS GUN TRAIN

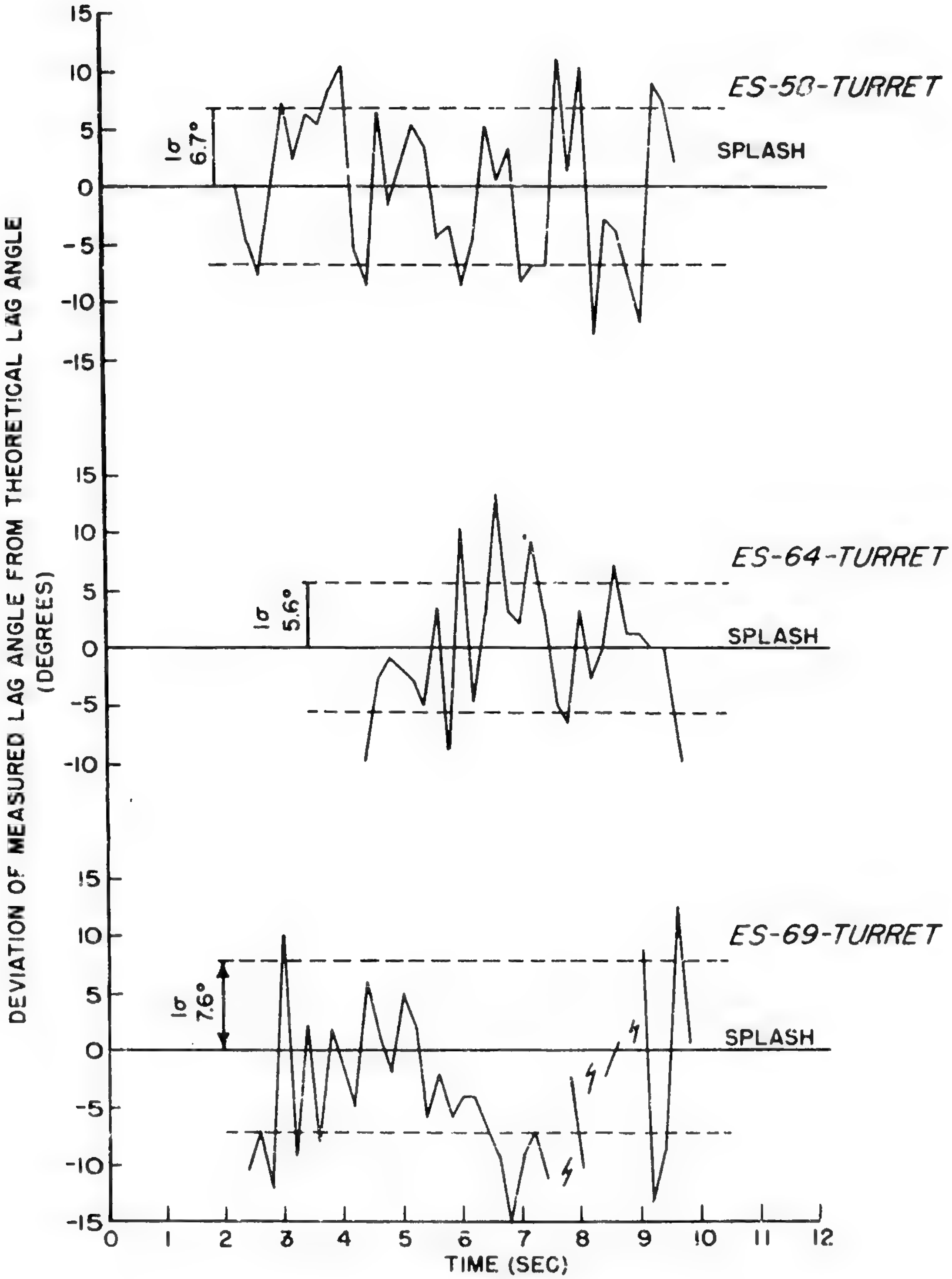
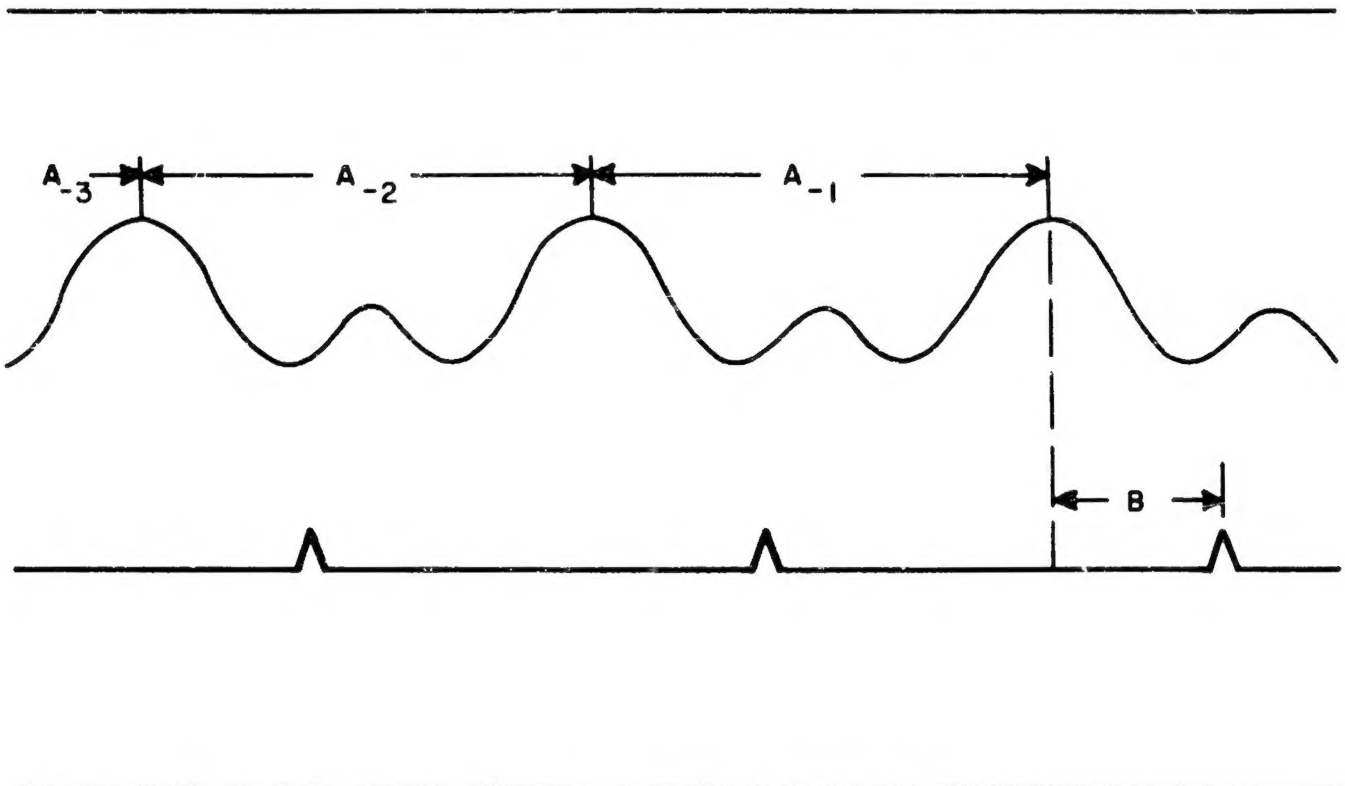


FIG. 12 SPIN ANGLE ERROR VS TIME FOR THREE LOW ELEVATION ROUNDS



MEASURED LAG ANGLE (1) = $360 \times \frac{B}{A_{-1}}$

MEASURED LAG ANGLE (3) = $360 \times \frac{3B}{A_{-1} + A_{-2} + A_{-3}}$

FIG. 13 METHOD OF SIMULATING THE OPERATION OF THE PERFECT TRANSLATOR

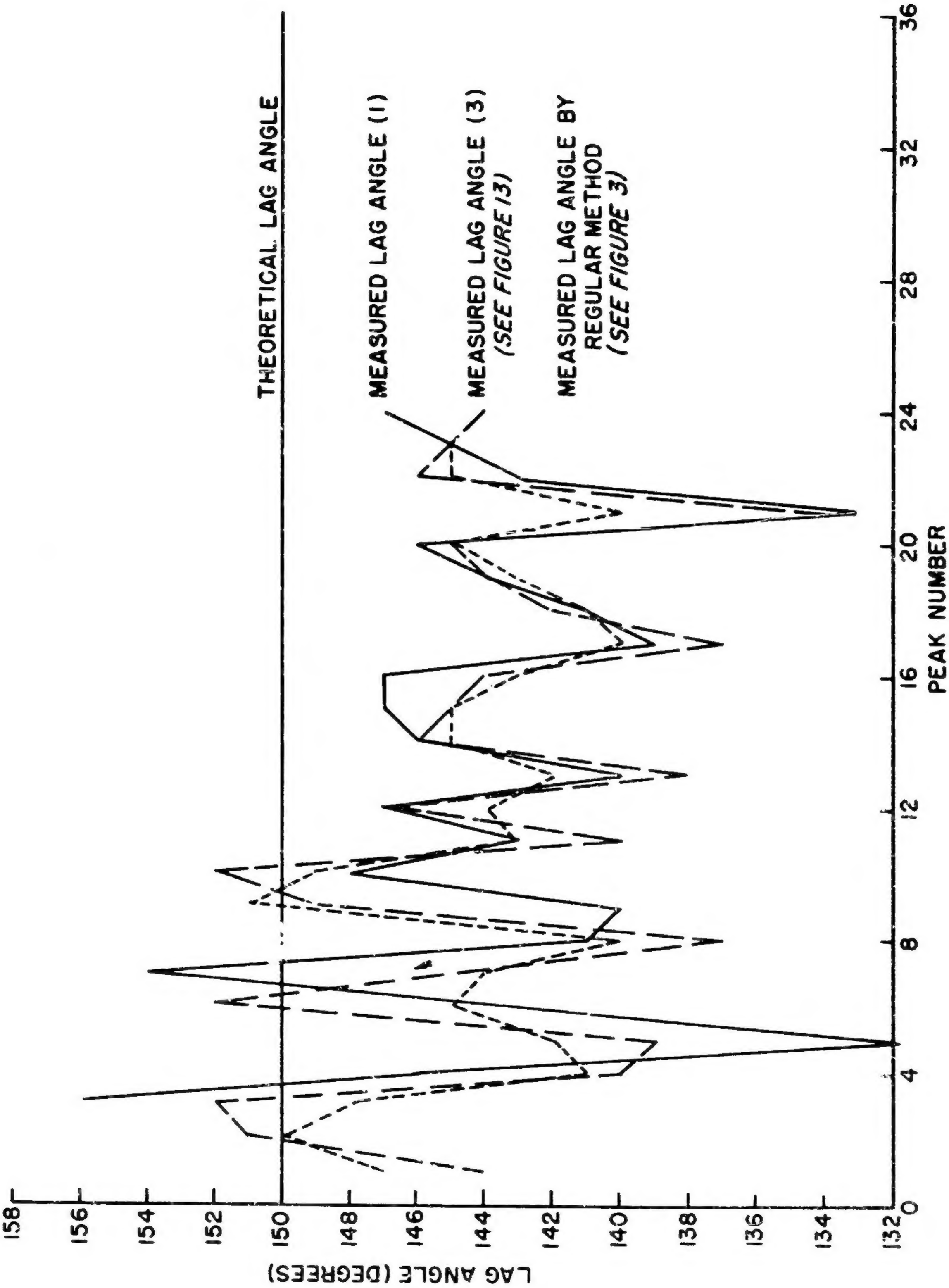
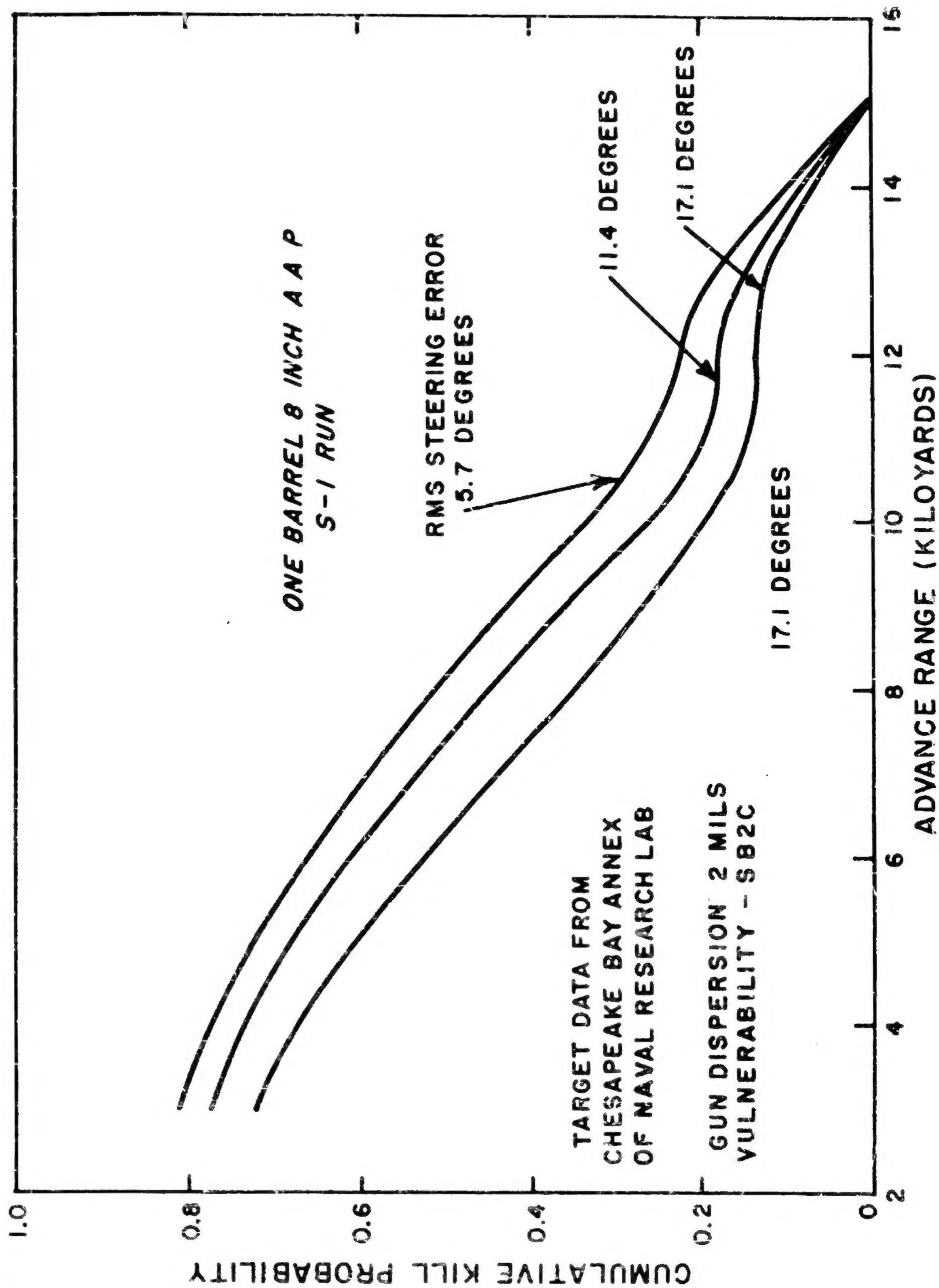


FIG. 14 SPIN ANGLE ERROR BY EXTRAPOLATION

FIG. 15
EFFECT OF STEERING ACCURACY ON CUMULATIVE "A" KILL PROBABILITY



SUMMARY OF DATA FROM SONDE RECORDS

Sonde No.	Gun Position		Error RMS difference between measured and theoretical lag angles			Bias average difference between measured and theoretical lag angles			Number of lag angle readings			Time interval read seconds from gun launching			Range of elevation angle of line of sight to missile		
	Train	Elev.	Bow	Turret	Director	Bow	Turret	Director	Bow	Turret	Director	Bow	Turret	Director	Bow	Turret	Director
							30 DEGREE ANTENNA ELEVATION										
ES-58	00	10	- -	6.7	- -	- -	.05	- -	- -	38	- -	- - -	2.2 - 9.6	- -	- -	7.8-0.3	- -
ES-49	00	20	- -	7.3	- -	- -	-4.2	- -	- -	76	- -	- - -	3.0-17.8	- -	- -	17.5-2.5	- -
ES-91	00	30	- -	5.3	- -	- -	-.6	- -	- -	58	- -	- - -	2.6-14.0	- -	- -		- -
ES-66	00	39	5.8	- -	- -	1.6	- -	- -	52	- -	- -	3.1-13.5	- - -	- -	37.0-27.0	- -	- -
ES-84	00	39	- -	7.4	5.5	- -	-5.8	0.8	- -	72	80	- - -	3.8-18.0	2.2-18.0	- -	36.3-22.3	37.8-22.3
ES-64	30	10	5.5	5.6	- -	3.6	.03	- -	29	28	- -	4.0-9.6	4.4-9.8	- -	6.0-0.3	5.5-0.2	- -
ES-70	30	20	4.5	5.4	- -	1.3	-0.6	- -	47	75	- -	8.86-17.06	3.0-17.8	- -	11.6-3.5	17.5-2.4	- -
ES-88	30	35	- -	6.9	10.0	- -	-3.6	4.5	- -	65	26	- - -	3.2-16.0	5.0-15.4	- -	31.3-19.5	30.5-20.0
ES-90	30	20	3.3	- -	- -	0.3	- -	- -	50	- -	- -	8.0-17.5	- - -	- -	13.0-3.0	- -	- -
ES-92	60	20	- -	6.3	7.4	- -	-4.4	-1.5	- -	75	75	- - -	3.0-17.8	3.0-17.8	- -	17.5-2.5	17.5-2.5
ES-89	60	35	3.4	5.4	8.2	-0.8	-1.9	6.5	100	74	73	4.75-20.0	2.4-17.0	2.4-17.0	30.8-15.0	33.0-18.8	33.0-18.8
ES-69	90	10	- -	7.6	8.0	- -	-3.5	-0.5	- -	34	35	- - -	2.4-9.8	2.4-9.8	- -	7.6-0.2	7.6-0.2
ES-67	90	20	6.0	6.8	8.9	0.8	2.1	5.4	40	60	64	4.0-12.8	2.8-15.0	2.0-15.0	16.5-7.5	17.6-5.8	18.3-5.8
ES-87	90	30	6.1	7.3	9.6	-3.8	-1.3	3.7	30	88	83	4.8-15.6	2.6-20.0	2.6-20.0	25.6-14.8	27.5-9.8	27.5-9.8
ES-86	120	20	6.3	6.1	10.6	3.0	-2.6	-6.2	29	33	32	3.0-14.0	3.0-16.0	3.0-16.0	17.5-17.0	17.5-4.7	17.5-4.7
ES-56	120	35	5.3	5.5	8.1	-0.2	0.5	1.6	86	86	79	3.0-20.0	3.0-20.0	4.4-20.0	32.5-15.0	32.5-15.0	31.2-15.0
ES-75	145	20	12.8	7.9	11.0	8.1	-2.4	6.1	61	61	61	4.0-16.0	4.0-16.0	4.0-16.0	16.6-8.6	16.6-4.6	16.6-4.6
ES-83	145	35	7.7	5.1	15.1	-1.5	0.2	3.8	58	67	56	3.03-15.07	3.0-18.6	3.0-18.6	32.5-20.5	32.5-16.5	32.5-16.5
OVERALL ANT. AVERAGES =			6.5°	6.5°	9.4°	1.0	-1.8	2.6									
OVERALL N.E.L. " =			2.8°	3.4°	4.8°	- -	- -	- -									
							0 DEGREE ANTENNA ELEVATION										
ES-66	00	39	- -	9.3	14.8	- -	3.4	8.7	- -	53	66	- - -	3.6-16.0	3.6-16.0	- -	36.5-24.5	37.0-24.5
ES-84	00	39	4.3	- -	- -	2.8	- -	- -	30	- -	- -	3.0-8.5	- - -	- -	37.0-32.0	- -	- -
ES-80	30	10	5.7	6.3	8.6	-1.0	0.3	-0.7	31	20	20	3.4-9.4	5.8-9.6	5.8-9.6	6.5-0.6	4.2-0.3	4.2-0.3
ES-73	30	38	8.0	9.5	14.6	-2.5	1.3	3.6	80	84	79	3.4-20.0	3.4-20.0	3.4-20.0	34.3-18.0	34.3-18.0	34.3-18.0
ES-71	90	35	8.1	11.0	11.5	-1.4	-6.5	2.0	76	73	70	2.8-18.0	3.6-18.0	3.6-18.0	32.6-17.3	31.9-17.3	31.9-17.3
ES-81	145	35	- -	8.2	22.1	- -	-2.0	8.7	- -	85	79	- - -	1.2-18.0	2.2-18.0	- -	34.0-17.3	33.1-17.3
OVERALL ANT. AVERAGES =			7.3°	9.3°	16.0°	-1.2°	-4.0°	5.3°									